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SOME: An Alternative Environment-friendly Internal Combustion engine fuel

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Abstract- In this work, an Alkalis catalysed transesterification was used to obtain Sorrel Oil Methyl Ester (SOME) from Sorrel Seed oil. The produced SOME had fuel properties which satisfied both ASTME D6751 and EN 1424 standards. The fatty acid profile of the SOME revealed the dominant fatty acids were oleic (58.337%), linoleic (21.194%), palmitic (18.280%), Emission assessment of SOME in an Internal combustion engine revealed 70% decrease in CO, 80% decrease in NO, 97% decrease in mass of oxygen in the blending, 59% increase in power and 45% decrease in SFC, respectively at B40 when compared to pure diesel (AGO). Hence, it can be concluded that B40 (40% SOME + 60% AGO) will provides the best emission reduction in an internal combustion engine.

Keywords: Sorrel oil methyl ester (SOME), Alkalis catalyzed transesterification, Fatty acids profile, Internal combustion engine, Exhaust emissions.

1. Introduction

Few people realize that vegetable oilseeds can be used for more than frying fast food. Indeed, Rudolph Diesel's first public exhibition of the internal combustion technology that was to later bear his name featured an engine running on peanut oil. He envisioned freeing small businesses from the monopolistic coal and steam power of the day by using organic fuels in his engine. Unfortunately, it turned out that his engine also lent itself to burning low-grade fractions of petroleum, and the rest is history. Diesel engine manufacturers optimized the design for lighter oils, and the use of vegetable oil never really got a chance. But researchers throughout the world have been reviving Diesel's vision, and vegetable oilseeds are finding increasing use, particularly in the US, UK, Germany, and Australia.

Because of this heritage, the fuel injection pump and the fuel injectors in modern diesel engines won't work on room temperature vegetable oilseeds because of its thickness [1]. However, there are three common ways to thin vegetable oilseeds so it can be used in diesel engines, this includes; blend the vegetable oil with a lighter fuel, heat the vegetable oil until it becomes thin enough, and changing the chemical composition of the vegetable oil [2].

Blending is fraught with problems, and although some enthusiasts swear by it, others end up swearing at it, as they damage expensive injection pumps with the heavier fluid. Some have suffered explosions when trying to mix extremely lighter fuels, like gasoline, with vegetable oil. Those reporting success seem to be limited to a mix no more than 50/50 with petro-diesel at no colder than "shirt sleeve" temperatures, on a few engines that have very robust injection pumps. The process of heating vegetable oil to about 80°C (or about 180°F) decreases its viscosity, easing its way through pumps and injectors, which cools and gels. This causes damage to the engine and can also result in a lot of heat wastage [3]. The presence of impurities in the oil and water in the fuel can also cause expensive engine damage. But, the method of changing the chemical composition, also known as transesterification process (biodiesel), is safe, reliable, cost effective, reduces pollution, and will work in almost any diesel engine without modification [3,4].

Internal combustion (I.C.) engines play a major role in transportation, industrial power generation and in the agricultural sector. There is a need to search and find ways of using alternative fuels, which are preferably renewable and also emit low levels of gaseous and particulate pollutants in internal combustion engines. As per the literature survey, fuels like vegetable oils, biodiesel (transistorized vegetable oils to methyl esters), alcohols, natural gas, biogas, hydrogen, liquefied petroleum gas (LPG), etc. are being investigated by researchers for engine applications. In the case of agricultural applications, fuels that can be produced in rural areas in a decentralized manner, near the consumption points will be favoured [4, 5]. The permissible emission levels can also be different in rural areas as compared to urban areas on account of the large differences in the number density of engines [6]. Many researchers have worked on the conversion of edible and non-edible vegetable oilseeds such as beniseed (*Sesamum indicum*), Sand box oil (*Terminalia catappa*), coconut oil, linseed, Jatropha, Karanja (*Pongamia glabra*), kusum (*Schlerlchera trijuga*), pongamia, etc, to biodiesel, separately to study the performance and emission characteristics of I.C. engine [1,2,3,4]. However, competitions for commercial edible vegetable oilseeds which are obtainable from just about a dozen species of plant have necessitated the search for oils from underutilized tropical plants such as *Hibiscus sabdariffa* (Sorrel seed) oil. Despite the potential of this under-utilized species as a source of less consumed food and medicine, to authors' best knowledge, sparse information is available on the suitability of its biodiesel in I.C. engine whose emission characteristics hitherto remains untapped. Hence, the study is focused on providing an alternative environmental-friendly internal combustion engine fuel from Sorrel seed oil.

2. Materials and Methods

2.1 *Materials*

The Sorrel seed oil used for this study was collected from the Department of Biochemical Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria. The convectional fuel (AGO) was purchased from petrol station in Omu-Aran, Nigeria. All chemicals such as Methanol (CH_3OH), potassium hydroxide (KOH), anhydrous calcium chloride ($CaCl_2$), sodium hydroxide pellet (NaOH) etc. were all of analytical grade.

2.2 *Experimental procedure*

2.2.1 Alkalis catalyzed transesterification

According to the method of [7], the transesterification reaction of Sorrel seed oil was carried out in a reactor flask placed on a hot plate with magnetic stirrer. The reactor was charged with a known weight of the oil sample at a known heating time for oil pre-heating at a temperature of 140 ^{0}F, the stirrer was kept to rotate at a speed of 600 rpm. After the heating has been completed, a known weight of NaOH pellet used as a catalyst was dissolved in a known volume of anhydrous methanol and was quickly transferred into preheated oil on the hot plate with magnetic stirrer and two layers was noticed. The reactor was covered by the stopper to prevent methanol escaping as the reaction proceeded. The hot plate was then adjusted to the desired temperature for complete reaction at a particular time.

At the end of the experiment the resulting mixture was then transferred to a separating funnel for glycerol and methyl ester separation, the glycerol was allowed to separate by gravity for 24 h. Two phases separated clearly, the less dense methyl ester at top and the denser phase of glycerol at bottom. The glycerol was then tapped off the bottom of the separating funnel leaving behind methyl ester in the separating funnel. Since the purity level of the biodiesel has strong effects on its fuel properties, therefore the methyl ester left in the funnel was then washed with distilled water to remove residual catalyst, glycerol, methanol and soap. The water being denser than the methyl ester settled at the bottom of the funnel and was tapped off slowly. The washing process was carried out in triplicate until the water becomes clear. The washed methyl ester left in the separating funnel was then tapped off into a Pyrex flask where it was further dried over heated calcium chloride powder placed on heating mantle to absorb the untapped water. The dried methyl ester obtained was decanted into a clean Pyrex flask to remove the hygroscopic calcium chloride sediment at the bottom of the heated flask. The final product was the Sorrel oil methyl ester (SOME) a biodiesel and the yield was calculated in terms of % (w/w) as described in Eqn. 1.

$$SOME\ \%\ (w/w) = \frac{Weight\ of\ oil\ biodiesel\ produced}{Weight\ of\ oil\ sample}\ X\ 100 \quad (1)$$

2.2 *Physicochemical analysis of the Sorrel oil and SOME*

The evaluation of physicochemical and other properties of the oil and SOME was determined by Wijs method [8] and the AOAC methods [9]. The quality of biodiesel is very important for the performance and emission characteristics of a diesel engine. Thus, the SOME produced was sent to the Nigeria National Petroleum Company (NNPC) Laboratory for Gas Chromatography Analysis to evaluate the fatty acids profile of the SOME.

2.3 *Emission Characterization of SOME on I.C. engine*

AGO was blended with the SOME in the ratio of 1:9; 2:8; 3:7; 4:6; to 9:1. The blends ratio was chosen in order to predict the emissions characteristics at any different ratios. 100% AGO and 100% SOME were also investigated for the emissions characterization. These blends were burnt in I.C. engine in succession and the emissions of NO and CO was recorded using TOXIRAE II Gas analyzers. The gas flue temperature was taken using K-type thermocouple which is capable of measuring up to 250 ^{0}C. The speed of I.C. engine was also taken by Tachometer at range 600-1000, 1100 – 1500, 1600 – 2000 and 2100 – 2500 rpm for different blends. The valuation process was simulated for various blends ratios to attained average data for errors minimization using Microsoft excel 8.0. Specific Fuel Consumption (SFC), mass of oxygen in the blends (Mo) and power output of the engine at various blends were calculated using Eqns 2, 3 and 4.

$$M_O = 0.34\rho_1 V_1 + 11\rho_2 V_2 \quad (2)$$

$$Power = 2\pi N\mathrm{T} \quad (3)$$

$$SFC = \frac{Volume\ of\ fuel\ used\ in\ Litre}{Power\ x\ Time} \quad (4)$$

3.0. Results and Discussion

3.1 *Physicochemical analysis and other properties of Sorrel seed oil and SOME*

3.1.1 *Physical properties of the Sorrel seed oil and SOME*

In order to evaluate the quality of the crude Sorrel oil and SOME, the content and compositions was subjected to physicochemical analysis and the results obtained are shown in Table 1. At room temperature the oil was greenish yellow in colour and the SOME was light yellow. There was a slight increase in refractive index, but the moisture content on wet basis decreased after conversion of oil to SOME, indicating a good shelf life characteristic of Sorrel seed oil. Observations on the colour, moisture content and refractive index of the oil and SOME agreed with previously published report [10]. The specific gravity of the oil was determined as 0.886 which was reduced to 0.862 after conversion, indicates that the Sorrel oil and SOME are less dense than water with refractive index of 1.4603 and 1.4610, respectively. The specific gravity reported by [12] ranged between 0.874 - 8.2312 for most of the vegetable seed oils. The viscosity, which is a measure of the resistance of material to shear, was determined to be 15.40 cP and 2.78 cP, respectively. The higher value obtained for the oil in this study indicates the oil could be used as lubricant in engine parts in the tropics if left overnight as solidification temperature of the oil is below 10 ^{0}C at any season [13]. The densities obtained in this work were in line with what was obtained by [10].

3.2.2 *Chemical properties of the Sorrel seed oil and SOME*

The results of chemical properties of the oil and SOME are also shown in Table 1. The low acid value of the seed oil (0.80 mg KOH/g oil) showed that the oil could not only be used for biodiesel production but also could serve as edible oil. This can be used to check the level of oxidative deterioration of the oil and biodiesel by enzymatic or chemical oxidation. The acid value earlier reported by expected by [11] was in the range of 0.00 - 3.00 mg KOH/g material. A high Saponification value (197.75 mg KOH/g oil) was obtained for the seed oil, suggesting high concentration of triglycerides which make it suitable for biodiesel production. The iodine value of the seed oil was high (97.77 g of I_2/100 g of oil), which signified the oil contained a substantial level of unsaturation and could be used to quantify the amount of double bonds present in the oil which reflects the susceptibility of oil to oxidation before conversion to SOME. Peroxide value measures the content of hydro-peroxides in the oil and its low value indicates high resistance to oxidation. The value obtained for the seed oil and SOME in this work were well within the limit stipulated for vegetable oils and biodiesel. This shows that the oil is not rancid and considered stable [14]. The Higher heating value (HHV) determined for the oil was 39.28 MJ/kg and it is within the range earlier reported [15] for vegetable oils (37.47 – 40.62 MJ/kg). The rise in the HHV after conversion of Sorrel seed oil to SOME proved that the oil is not only good for biodiesel production, but can be suitably used as fuel in I.C. engine.

3.2.3 Other properties of the Sorrel seed oil and SOME

Additional fuel properties such as cetane number, API, diesel index, mean molecular mass and aniline point of the oilseed and SOME were determined (Table 1). Cetane number is a measure of the fuel's ignition delay and combustion quality. Minimum standard specification for cetane number for biodiesel is 40 [16]. The cetane number of the Sorrel seed oil and SOME was found to be 51.90 and 68.54, respectively, showing that both the oil and the SOME have high fuel potential. The cetane number reported for most vegetable oils range from 27.6 to 52.9 [15, 17]. The API, diesel index and aniline point of the Sorrel seed oil and SOME were comparable with other reported work [9]. The transesterification of the Sorrel seed oil to SOME therefore improved its fuel properties.

3.3 Fatty acid profile of SOME

Gas chromatography (GC) analyses of fatty acids present in the SOME are shown in Table 2. The results indicated that SOME is highly unsaturated. The dominant fatty acids were: oleic (58.337%), linoleic (21.194%), palmitic (18.280%), stearic (0.213%), linolenic acid (C18:3) (0.165%), arachidonic acid (C20:4) (1.548%) and others (0.263%). The values observed in this work are within the ranges previously reported [18, 19]. This indicates that fatty acid composition will play a dominant role in establishing the cetane number [19, 20].

3.4 Fuel Stability and Emissions from Combustion of SOME

Emissions test was conducted on a four stroke, air cooled, single cylinder direct injection diesel engine, developing a power output of 3.23 kW at a speed of 2600 rpm. Table 3 shows the specifications of the engine used for the combustion emission. The emissions of NO and CO were measured from combustion of fuel in I.C. engine. The valuation process was simulated for various blends ratios to attained average data for errors minimization using Microsoft Excel 8. NO and CO were measured using combustion analyser, flue gas temperature (T_g) was measured using a thermocouple, power output of the engine was measured using Photo contact Tachometer, while, specific fuel consumption (SFC), mass of oxygen in the blends (Mo) and at various blend were computed. Figures 1 to 5 show the plots of the results collected.

3.4.1 Specific fuel consumption Vs. SOME/AGO Blends

Figure 1 shows the SFC data obtained from various blends at different speeds intervals. As the speeds increased, the rate of fuel consumption increases. Hence, more heat is released during firing [21]. The higher the speed range of I.C. engine, the more the SFC rate at various blend ratio except at B50 where the fuel consumption volume at speed of 600 - 1000 rpm was the highest. Blends at speed 2100-2500 rpm consumed more fuel than the corresponding blends at various speeds range. The plot shows the percentage reduction in specific fuel consumption at speed range of 600 - 1000 rpm to be 45% when compared with 100% AGO. This was in agreement with what was reported by [22].

3.4.2 Power Vs. SOME/AGO Blends

From Figure 2, it was observed that the power produced by the I.C. engine was high at the highest speed (2100 - 2500 rpm) than the power obtainable at the lowest speeds ranges except at B40, where the power of engine at 1600 - 2000 rpm gave high values. This higher values obtained at various speeds showed that the blend of Sorrel biodiesel with AGO does not need any other additives for optimization as reported [23]. It was observed that B70 at speed range 600 - 1000 rpm has the lowest power. This showed that engine power reduces with the increase in blends of the oxygenated compound [24]. The percentage reduction in power at B70 was calculated to be 59%. This may be due to latent heat of vaporization which required some amount of energy of SOME during fuel injection in combustion chamber [24].

4.4.3 Percentage mass of oxygenVs. SOME/AGO Blends

Figure 3 describes the plot of percentage mass of oxygen vs. SOME/AGO blends. It was observed that at highest speed range of 2000 - 2500 rpm, the percentage Mo minimum in the fuel was higher than other at lowest speed ranges. This is an indication that when the oxygen concentration in the fuel increases, the CO concentration decreases. This was due to Sorrel biodiesel which contain oxygen in it molecular structure and therefore require lesser oxygen molecule to complete combustion. On the other hand, the carbon to hydrogen ratio of diesel is 18:1 [24]. This means to have a complete combustion, 1 g of diesel required significant amount of oxygen. However, SOME can have complete combustion with lesser amount of oxygen due to its composition. For this reason, increasing SOME in blends will reduce CO and mass of oxygen concentration with complete combustion [24]. The graph also shows a linear negative slope with intercept at various plots. The values of R^2's showed that the reaction that took place during firing in I.C. engine via blends ratio were of first order reaction. The percentage Mo obtained in the blends at speeds range (1100 - 1500 and 1600 - 2000 rpm) of the engine was nearly the same. The percentage reduction in percentage mass of oxygen of 100% SOME was calculated to be 97%.

4.4.4 CO and NO Vs. SOME/AGO Blends

Figures 4 and 5 described the plots of CO and NO Vs. SOME/AGO Blends, respectively. For CO monitoring, the lowest values of the pollutant was observed at engine speed range of 1600 - 2000 rpm while the highest levels of the pollutant was observed at 600 - 1000 rpm. Whereas for

NO monitoring, the lowest value of the pollutant was observed at 2100-2500 rpm and the highest level of the pollutant was observed at 1100 - 1500 rpm. The results revealed 70% reduction of CO at B80 and 80% reduction of NO concentration at B40.

4. Conclusion

The results obtained in this study revealed that Sorrel seed oil is a good material for SOME production. The produced SOME had fuel properties which satisfied both ASTME D6751 and EN 1424 standards. GC analyses of fatty acids present in the SOME revealed that SOME is highly unsaturated with dominant acid: oleic (58.337%), linoleic (21.194%), palmitic (18.280%), Emission assessment revealed 70% decreased in CO, 80% decreased in NO, 97% decreased in mass of oxygen in the blending, 59% decrease in power and 45% decreased in SFC, respectively at B40.

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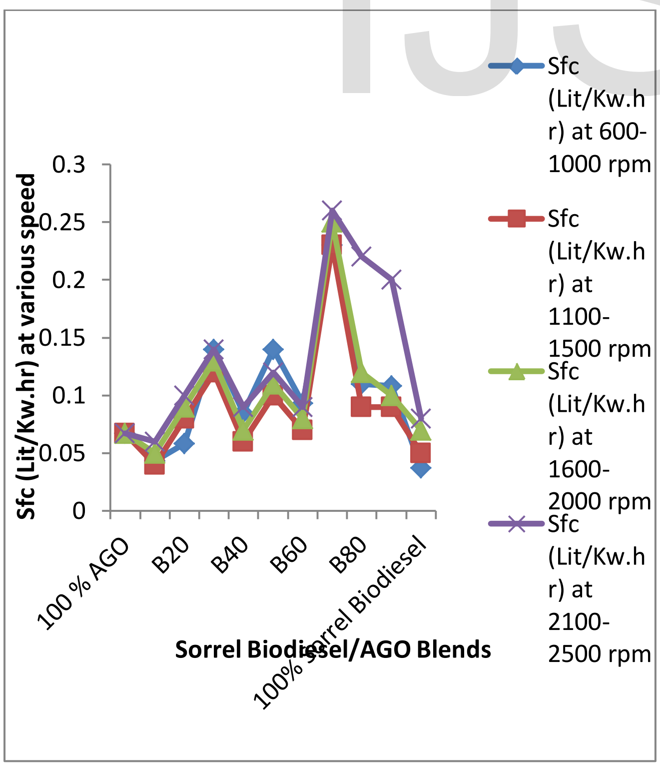

Fig. 1 : Specific fuel consumption vs SOME/AGO blends

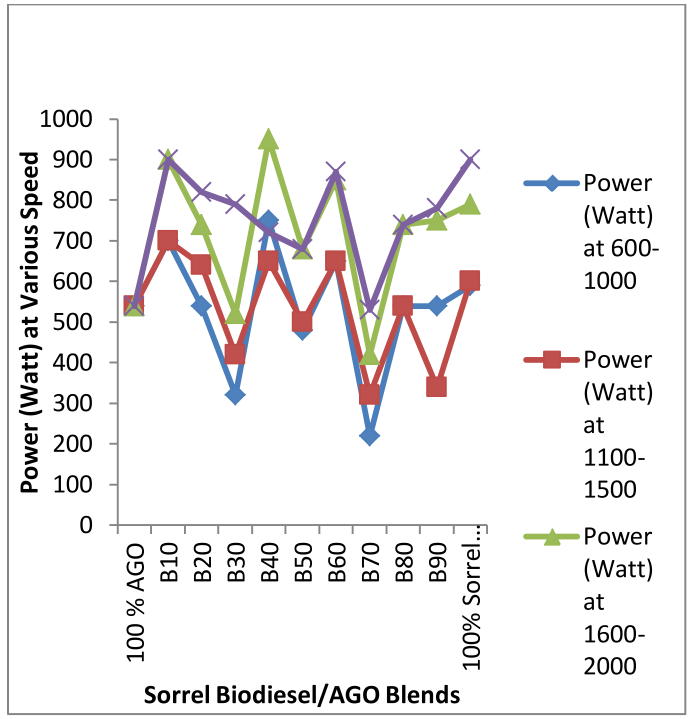

Fig.2 : Graph of power vs SOME/AGO blends

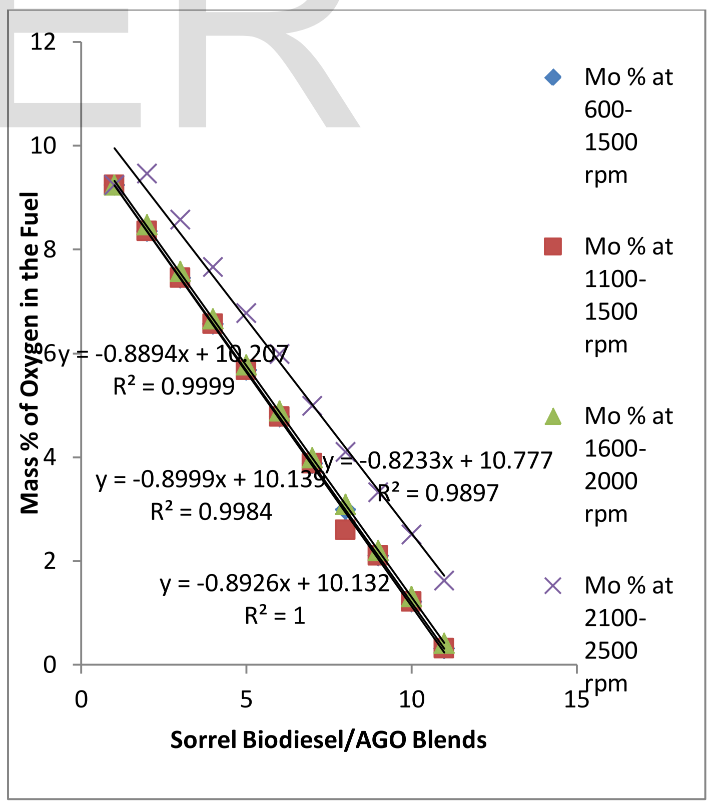

Fig. 3: Mass of oxygen in the fuel vs SOME/AGO blends

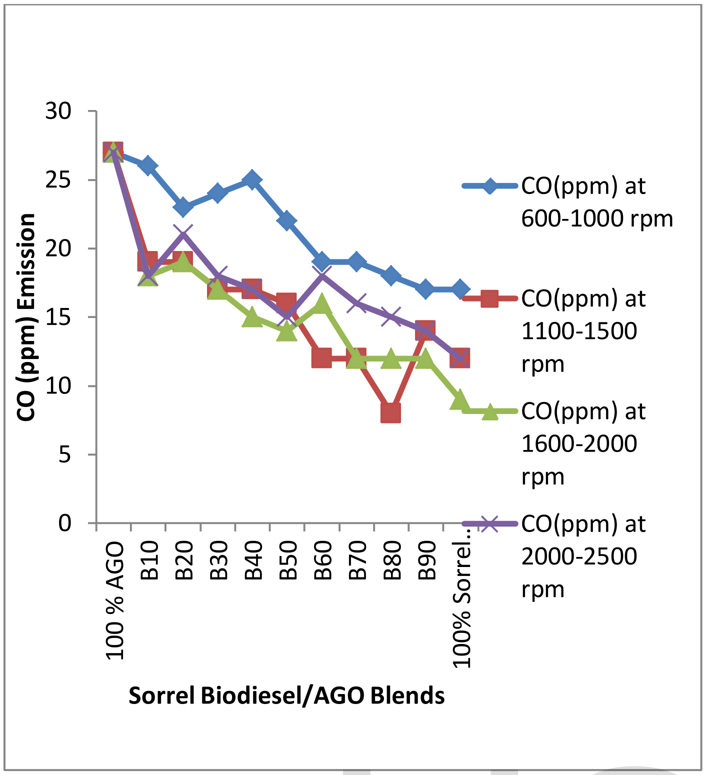

Fig. 4: Graph of CO Emission vs SOME Blends

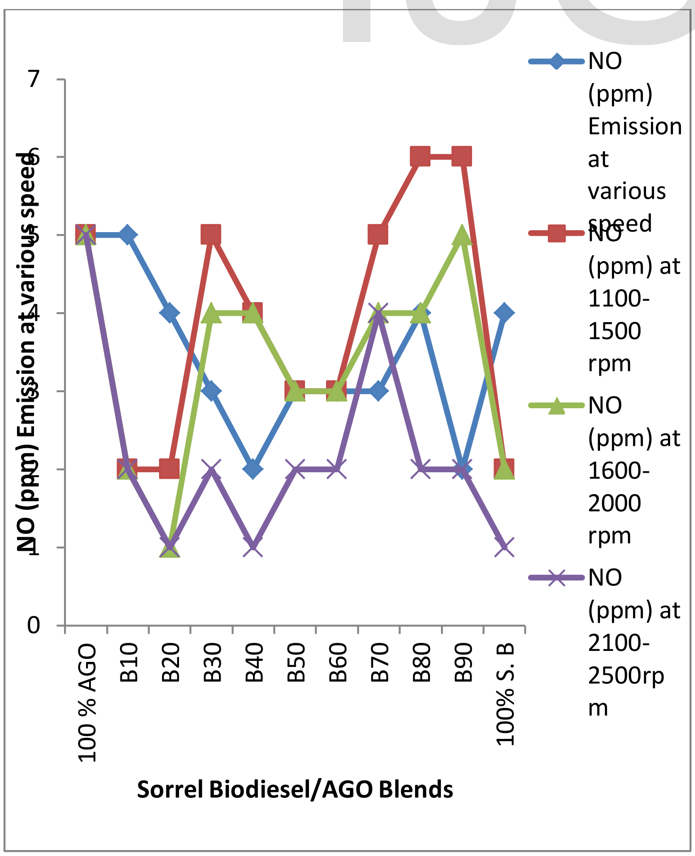

Fig. 5 : Graph of NO emission vs SOME/AGO blends

Table 1: Properties of Sorrel Seed Oil and SOME in Comparison with Biodiesel Specification

Parameters	Sorrel Seed Oil	SOME	ASTM D6751	EN 14214
Physical properties				
Physical state	Liquid/greenish yellow	Liquid/ Light yellow	-	-
Refractive index at 25°C	1.4603			
Moisture content % (wet basis)	0.065	0.001	0.05 max	0.02
Specific gravity at	0.886	0.862	0.86-0.90	0.85
Viscosity (Cp) at 40°C	15.40	5.80	1.9-6.0	3.5-5.0
Chemical properties				
Iodine value (g I_2/100g)	97.77	64.47	-	120 max
%FFA (as oleic acid)	0.40	0.48	-	-
Acid value	0.80	0.24	< 0.80	0.5 max

Saponification value (mg KOH/g oil)	197.75	148.49	-	-
Other properties				
Higher heating value (MJ/kg)	39.86	42.48	-	-
Diesel index	58.19	81.94	50.40	-
API	28.21	32.65	36.95	-
Aniline point (°F)	121.11	250.96	331.00	-
Cetane number		69.00	47 min	51 min
Flash point (°C)		186	93 min	>120 min
Cloud point (°C)		+5	-	-
Pour point (°C)		-15	- 15	-

Table 2: Fatty Acids Compositions of the Sorrel Seed Oil and SOME Produced

Parameters	Compositions %	
	Sorrel Seed Oil	SOME
Palmitic acids (C16:0)	12.684	18.280
Stearic acids (C18:0)	10.865	0.213
Oleic acids (C18:1)	30.061	58.337
Linoleic acids (C18:2)	44.390	21.194
Others	2.000	1.976
Total	100	100

Table 3: Engine specifications

Parameter	Specification
Type of engine	Single cylinder
Engine brand name	165F, Direct injection, four-stroke, Internal Combustion Engine.
Stroke length	0.11 m
Bore and stroke	87.5 mm x 110 mm
Cooling method	Air
Injector operating pressure	200 bar/ 23 °C BTDC
Dynamometer current	Eddy current
Compression ratio	16.5:1
Response time	4 micro seconds
Rated speed	2600 rpm
Resolution in 1 degree	360 degree encoder with a resolution of 1

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Rated power	3.2 Kw